6-1000 OPEN CHANNELS

6-1001 Water Surface Profiles (Standard Step Method and Direct Step Method)

6-1001.1 Water surface profiles for steady flow in non-uniform channels with frequent changes of cross-section and grade, and uniform channels with frequent changes of grade cannot be computed accurately by assuming uniform flow conditions where there is no appreciable length of constant section and grade and there is no opportunity for conditions of uniform flow to exist.

6-1001.2 Water surface profiles for steady flow in channels of this type are determined by computing separately and successively the change in surface elevation in each of a number of small portions of the total length of the profile.

6-1001.2A These small portions, called reaches, must be short enough to reduce to a permissible magnitude the error in approximating the true slope of the water surface profile through the reach by the average of the surface slopes at each end, or by the slope corresponding to the average of the hydraulic properties of the reach.

6-1001.2B These reaches shall be selected with due regard to the irregularities in the channel.

6-1001.2C The step computations are carried upstream if the flow is subcritical and downstream if the flow is supercritical.

6-1001.3 Various textbooks and publications on open-channel hydraulics explain in detail the step method of computing water surface profiles for prismatic and non-prismatic channels.

6-1001.4 Flow profiles by The Standard Step Method and Direct-Step Method have been programmed for the electronic computer. Employment of these programs should not be attempted without a knowledge of energy balance and without prior experience of working flow profiles by the manual method.

6-1002 Side Ditches and Median Ditches

6-1002.1 As the necessity arises, special procedures and nomographs are developed to be used to facilitate repetitive design. Charts of the side and median ditch series have been developed to facilitate and simplify the design (See VDOT Drainage Manual).

6-1002.2 Side and Median Ditch Design. Follow the general procedure outlined below (see also § 6-1010):

6-1002.2A Note on the computation form, under Station to Station, points at 100' (30m) intervals where roadside ditches, median ditches or valleys, formed by fill slope and inward sloping existing ground, will be constructed.

6-1002.2B Note, by flow arrow on the form, the direction the flow will take in the side ditch.

6-1002.2C Note the average width of the strip to be drained. Use of the cross-sections, contour maps or aerial photos will facilitate this operation.

6-1002.2D Determine the design discharge, for each 100' (30m) interval point, starting at the first point down grade from the peak in the ditch grade and proceeding down grade. The following method of determining this "Q" will suffice: Compile a table of CA values that will cover the various width strips.

6-1002.2D(1) Multiply the appropriate CA value, or the sum of the appropriate CA values, by the rainfall intensity. The rainfall intensity will decrease approximately 0.1" (2.5mm) for each additional 100' (30m) the flow travels in the ditch.

6-1002.2D(2) The resultant "Q" is entered in the space provided on the form.

6-1002.2E Note the slope of the ditch flow line in the space provided on the form.

6-1002.2F Enter the appropriate Side Ditch Flow Chart with "Q" and slope to determine the velocity of flow using "n"=0.030 for unpaved ditches.

6-1002.2G Where the velocity, as determined above, exceeds the allowable velocity, as determined from the soil classification in the soils report, the ditch shall be lined.

6-1002.2G(1) To determine the depth of flow in the lined ditch, enter the appropriate Side Ditch Flow

Chart, using the appropriate "n" with "Q" and slope and read the depth of flow.

6-1002.2G(2) Standard paved ditches or special design paved ditches, gutters or channels having "D" dimension sufficient to cover the majority of the maximum depths noted on the computation form shall be required where the computations indicate the maximum allowable velocity is exceeded.

6-1002.2G(3) The "D" dimension shall be noted on the plans along with the standard used.

6-1002.2G(4) A typical section of all special design paved ditches, gutters, or channels shall be included in the plans.

6-1002.2G(5) Paved ditch construction specifications are shown in § 6-1013 and Plate 19-6 (19M-6) shows standard ditch sections. The ditch sections transitioning from full width to yard inlet are shown on Plate 20-6 (20M-6).

6-1002.2H A typical example will be found in § 6-1009, 6-1010 and 6-1011.

6-1003 Channel Charts. The trapezoidal channel charts of the CC series have been developed to supplement the Federal Highway Administration Publication (see VDOT Drainage Manual).

6-1004 Design Criteria

6-1004.1 In general, roadside and median ditches shall be designed with sufficient capacity to contain the runoff for a 10-yr storm. For determining whether or not special linings will be required and the lining dimensions, the 2-yr storm shall be used.

6-1004.1A (61-98-PFM) For an engineered grass swale, ditch or channel designed to convey stormwater within County easements provided for swales, ditches or channels, the maximum design velocity (V) shall be no greater than 4FPS (1.2 MPS), as determined by the formula cited in § 6-1005.1. Swales, ditches or channels exceeding these parameters will require special linings. This requirement does not apply to emergency spillways for dams. Vegetated spillway velocity requirements are included in § 6-1600.

6-1004.1B (61-98-PFM) All special channels shall be designed for storm frequencies in accordance with the importance of the road and its vulnerability to inundation, should the capacity be exceeded.

6-1004.1C (61-98-PFM) If the newly constructed channel (ditch) alongside, or leading from, any street providing access to lots to be occupied, or through, or alongside any such lots, is not well stabilized within 120 days after initial attempts to stabilize, or 120 days after issuance of any Residential or Non-Residential Use Permit for such lots, whichever occurs first, the channel (ditch) must be paved.

6-1004.2 In the event an exception for a winter Residential Use Permit is granted as provided for in Paragraph 2 of § 18-704 of the Zoning Ordinance, the 120 days shall run from March 15 of the following spring. "Well stabilized" shall mean a good stand of grass must be growing and not showing any visible evidence of erosive forces. Sod shall be growing well and knitted into the underlying soil.

6-1005 Channel Size and Shape

6-1005.1 The size of a channel shall primarily be established by the Manning Formula which may be expressed as:

$$Q = VA = 1.49/n\ r^{2/3}\ S^{1/2}\ A$$
$$(Q = VA = 1/n \times r^{2/3} \times S^{1/2} \times A)$$

Definitions of the terms are given in § 6-0902 (see Plate 27-6 (27M-6) and Table 6.17).

6-1005.2 General guidelines related to the size and shape of channels are:

6-1005.2A Low flow sections should be considered in the design of channels with large cross-sections.

6-1005.2B Channel bottom of widths greater than 10' (3m) shall be built with a minimum cross slope of 1:12.

6-1005.2C The side slopes of a channel shall be a function of channel material. The side slopes throughout the entire length of a channel shall be stable.

6-1005.2D Channels to be constructed on horizontal curves should be investigated to see if channel section needs to be modified. The superelevation of the water in the channel may be computed by:

e	=	$V^2 w/gr$
e	=	Difference in elevation between the water surface on the inside and outside walls of the channel in ft (m).
V	=	Mean velocity of flow in FPS (MPS).
w	=	Average width of channel in ft (m).
g	=	Acceleration of gravity, 32.2 FPS^2 (9.81 MPS^2)
r	=	Radius of channel centerline in ft (m). The rise in water surface may be accounted for by channel freeboard and/or superelevation of the channel sides.

6-1005.2E Minimum easement widths shall be determined as follows:

TABLE 6.16A
MINIMUM EASEMENT WIDTHS – CHANNELS

Top Width of Channel	**Easement Width**
< 2' (< 0.6m)	10' (3m)
2' – 4' (0.6m – 1.2m)	10' (3m) greater than top width of channel with minimum of 5' (1.5m) on 1 side.
> 4' (> 1.2m)	15' (4.6m) greater than top width of channel with minimum of 5' (1.5m) on 1 side.

Channels to be maintained by DPWES shall be within dedicated storm drainage easements.

6-1006 Channel Materials. Channel materials acceptable for open channel design with the accompanying roughness coefficients are shown below:

TABLE 6.17
CHANNEL MATERIALS – "n"

Material	**n**
Concrete, trowel finish	0.013
Concrete, broom or float finish	0.015
Gunite	0.018
Riprap placed (VDOT Class I)	0.030
Riprap dumped (VDOT Class I)	0.035
Gabion	0.028

6-1007 Energy and Hydraulic Gradients. (Reference Plates 24-6 (24M-6) through 26-6 (26M-6))

6-1007.1 The hydraulic gradient for an open channel system is the water surface. The energy gradient is a line drawn a distance $V^2/2g$ above the hydraulic gradient. At channel junctions, the total energy loss at the junction, H_L, is the difference in elevation between the energy grade lines of the upstream and downstream channels. To establish these gradients for a system, it is necessary to start at a point where the energy and hydraulic gradients are known or can readily be determined.

6-1007.2 Generally, when the energy and hydraulic gradients must be determined, the channels are assumed to have uniform flow. For uniform flow the friction loss along the channel may be determined by the Manning Formula as discussed above and in § 6-0902.

6-1007.2A Energy Loss at Channel Transitions. The energy loss for open channel transitions may be calculated by:

h_l	=	$k_l(V^2/2g)$
h_l	=	Energy loss at transitions due to change in flow area, slope, roughness or any combination of the characteristics.

$V^2/2g$ = Change in velocity head before and after the transitions. This value is always considered positive.

k_1 = 0.2 for channel expansion, i.e., velocities decreasing along direction of flow.

k_1 = 0.1 for channel contraction, i.e., velocities increasing along direction of flow.

Some general guidelines to the design of channel transitions are as follows:

6-1007.2A(1) Transition to channel connections should be connected with smooth tangent type surfaces.

6-1007.2A(2) A straight line connecting flow lines at the 2 ends of the transition should not make an angle greater than 12 1/2° with the axis of the channel.

6-1007.2A(3) Make transition length considerably greater than transition width.

6-1007.2B Energy Loss through Horizontal Channel Curve.

In addition to the friction loss through a channel curve, there is an additional energy loss due to the change in direction of flow. This loss may be calculated as follows:

h_2 = $k_2(V^2/2g)$

h_2 = Energy loss in a curved channel due to change in direction of flow.

k_2 = Energy loss coefficient which may be determined from Plate 25-6 (25M-6).

$V^2/2g$ = Velocity head in curve.

6-1007.2C Drop. If possible the energy losses through a transition or horizontal curve should be accounted for by an increase in channel slope through the transition and/or curve. The equations above and Plate 26-6 (26M-6) show the method for computing the drop.

6-1008 Channel Design Calculations. In general the following design calculations shall be required for submission of plans to the County:

6-1008.1 Design flows shall be determined by methods discussed in § 6-0800 et seq.

6-1008.2 Plans showing channels carrying flows no greater than 30 CFS (0.85 CMS) shall show channel capacity calculations.

6-1008.3 Plans showing channels carrying flows 30 CFS (0.85 CMS) and greater shall show:

6-1008.3A Channel capacity calculations.

6-1008.3B Calculations showing that freeboard requirements have been met.

6-1008.3C Energy and hydraulic gradients drawn on storm sewer profiles at channel transitions and/or curves.

6-1008.4 A note stating that "All grass-lined channels must be in a well stabilized condition and show no signs of erosion at the time of final acceptance by the maintaining authority" shall be shown on all applicable plans.

6-1009 Example – Paved Ditch Computations. Given or assumed (values vary with projects):

6-1009.1 Q=CIA; where C=0.9 for paved area, C=0.5 for unpaved drainage area within normal rights-of-way, C=0.3 for drainage area outside normal rights-of-way. "I" is based on the 2-yr rainfall curve with time of concentration dependent upon average width, grade and type of cover, (5% and average grass in this case).

$$A = \frac{100 \times \text{Width Strip}}{43{,}560}$$

A = area in acres
Width Strip = width in ft.

6-1009.2 Typical Section: 24' pavement, ditch having 3:1 front slope and 2:1 back slope.

6-1009.3 Soil Classification: ~~From Soils Report mostly class "c" with short section of class "d".~~From Virginia Erosion and Sediment Control Handbook, Chapter 5, mostly silt loam with a short section of ordinary firm load.

6-1009.4 Allowable Velocity: From Table 5-22 in the Virginia Erosion and Sediment Control Handbook~~6.19 the "Table of Allowable Velocities for Erodible Linings" (§ 6-1012) using column headed "Water Carrying Fine Silts",~~ use 3 FPS as permissible~~allowable~~ velocity for silt loam~~class "c"~~ and 3.5 FPS for ordinary firm loam~~class "d"~~.

6-1009.5 Normal right-of-way width = 110'.

6-1009.6 Width Strip Drained: To be determined from cross-sections, aerial photographs, topographical sheets or field observation (to be measured from outside edge of pavement to the nearest multiple of 10').

6-1009.7 (61-98-PFM) Where vegetative linings are used, n=0.050 should be used and a velocity of 4 FPS should be the upper permitted maximum.

6-1010 Example - Paved Ditch Computations. "C" "A" Values for 100' of ditch, using various widths and roughness factors.

		Col. 1 No Pavement	Col. 1 + 0.025* 12' Pavement	Col. 1 + 0.050** 24' Pavement	
$\frac{30 \times 100 \times 0.5}{43,560}$	=	0.035	0.060	0.085	***12' Pavement Computations**
$\frac{40 \times 100 \times 0.5}{43,560}$	=	0.046	0.071	0.096	$\mathbf{\frac{12 \times 100 \times 0.9}{43,560} = 0.025}$
$\frac{60 \times 100 \times 0.48}{43,560}$	=	0.066	0.091	0.116	****24' Pavement Computations**
$\frac{100 \times 100 \times 0.41}{43,560}$	=	0.094	0.119	0.144	$\mathbf{\frac{24 \times 100 \times 0.9}{43,560} = 0.050}$
$\frac{150 \times 100 \times 0.37}{43,560}$	=	0.128	0.153	0.178	
$\frac{200 \times 100 \times 0.35}{43,560}$	=	0.161	0.186	0.211	

Note: See § 6-1002 and VDOT Drainage Manual Section 2.7.3.

From 2-yr Curve – RAINFALL

Duration (minutes)	6	7	8	9	10	11	12	13	14	15
Intensity	4.8	4.6	4.4	4.3	4.1	4.0	3.9	3.7	3.6	3.5

TABLE 6.18 TIME OF CONCENTRATION TO USE – PAVED DITCH

30'	Width Strip	-	t_c	6 minutes,	I 4.8 in./hr
40'	Width Strip	-	t_c	7 minutes,	I 4.6 in./hr
60'	Width Strip	-	t_c	9 minutes,	I 4.3 in./hr
100'	Width Strip	-	t_c	10 minutes,	I 4.1 in./hr
150'	Width Strip	-	t_c	12 minutes,	I 3.9 in./hr

200' Width Strip - t_c 14 minutes, I 3.6 in./hr

6-1011 Example – Paved Ditch Computations. Decrease "I" value 0.1 in./hr for each additional 100' that water flows in the ditch.

Time of Concentration is based on Plate 4-6.

COMPUTATIONS

Sta. 136 + 00 to 142 + 00 and Sta. 149 + 50 to 157 + 50

Check Point	C A Values	CAI = Q
Sta. 137+00	0.060	0.060 x 4.8 = 0.2880 CFS
Sta. 138+00	0.071 0.131	0.131 x 4.6 = 0.6026 CFS
Sta. 139+00	0.119 0.250	0.250 x 4.1 = 1.0250 CFS
Sta. 140+00	0.119 0.369	0.369 x 4.0 = 1.4760 CFS
Sta. 141+00	0.071 0.440	0.440 x 3.9 = 1.7160 CFS
Sta. 142+00	0.071 0.511	0.511 x 3.8 = 1.9418 CFS
Sta. 156+50	0.096	0.096 x 4.6 = 0.6228 CFS
Sta. 155+50	0.116 0.212	0.212 x 4.3 = 0.9116 CFS
Sta. 154+50	0.144 0.356	0.356 x 4.1 = 1.4596 CFS
Sta. 153+50	0.211 0.567	0.567 x 3.6 = 2.0412 CFS
Sta. 152+50	0.211 0.778	0.778 x 3.5 = 2.7230 CFS
Sta. 151+50	0.178 0.956	0.956 x 3.4 = 3.2504 CFS
Sta. 150+50	0.119 1.075	1.075 x 3.3 = 3.5475 CFS
Sta. 149+50	0.091 1.166	1.166 x 3.2 = 3.7312 CFS

~~6-1012 ALLOWABLE VELOCITIES FOR ERODIBLE LININGS~~

~~TABLE 6.19 MAXIMUM ALLOWABLE VELOCITIES FOR ERODIBLE LININGS~~					
	~~Earth – No Vegetation~~	~~Clear Water FPS (MPS)~~	~~Water Carrying Fine Silts [Colloidal] FPS (MPS)~~	~~Water Carrying Sand & Gravel FPS (MPS)~~	~~Testing Division Classification~~
~~a.~~	~~Fine Sand [non-colloidal]~~	~~1.2 (0.37)~~	~~2.5 (0.76)~~	~~1.5 (0.46)~~	~~Beach Sand or A-3 soils.~~
~~b.~~	~~Sandy Loam [non-colloidal]~~	~~1.75 (0.53)~~	~~2.5 (0.76)~~	~~2.0 (0.61)~~	~~Highly micaceous soils. Non-plastic A-2-4(0) soils.~~
~~c.~~	~~Silt Loam [non-colloidal]~~	~~2.0 (0.61)~~	~~3.0 (0.91)~~	~~2.0 (0.61)~~	~~Low to medium micaceous soils. Non-plastic A-4 soils.~~
~~d.~~	~~Ordinary Firm Loam~~	~~2.5 (0.76)~~	~~3.5 (1.07)~~	~~2.25 (0.96)~~	~~Silty clays, Plastic A-4 & A-7-5 soils.~~
~~e.~~	~~Fine Gravel~~	~~2.5 (0.76)~~	~~5.0 (1.52)~~	~~3.75 (1.14)~~	~~Sandy granules [fine]~~
~~f.~~	~~Stiff Clay [very colloidal]~~	~~3.75 (1.14)~~	~~5.0 (1.52)~~	~~3.0 (0.91)~~	~~Clay soils [such as pipe clay] A-7-6 soils.~~
~~g.~~	~~Graded, Loam to Cobbles [colloidal]~~	~~3.75 (1.14)~~	~~5.0 (1.52)~~	~~5.0 (1.52)~~	~~Soil and rock, non-plastic [disintegrated stone].~~
~~h.~~	~~Graded, Silt to Cobbles [non-colloidal]~~	~~4.0 (1.22)~~	~~5.5 (1.68)~~	~~5.0 (1.52)~~	~~Soil and rock, plastic~~
~~i.~~	~~Alluvial Silts [non-colloidal]~~	~~2.0 (0.61)~~	~~3.5 (1.07)~~	~~2.0 (0.61)~~	~~Top soil, non-plastic~~
~~j.~~	~~Alluvial Silts [colloidal]~~	~~3.75 (1.14)~~	~~5.0 (1.52)~~	~~3.0 (0.91)~~	~~Top soil, non-plastic~~
~~k.~~	~~Coarse Gravel [non-colloidal]~~	~~4.0 (1.22)~~	~~6.0 (1.83)~~	~~6.5 (1.98)~~	~~Creek Gravel~~
~~l.~~	~~Cobbles and Shingles~~	~~5.0 (1.52)~~	~~5.5 (1.68)~~	~~6.5 (1.98)~~	~~Soft rock [can be loosened with rooter]~~

~~Note: 3 ½ FPS (1.07 MPS) is the maximum permissible with any soil type (no vegetation).~~

6-1012~~3~~ Paved Ditch Construction Specifications

6-1012~~3~~.1 All construction and materials shall conform, where applicable, to the current VDOT Road and Bridge Specifications except as noted herein:

6-1012~~3~~.1A The Director may require special designs for paved ditches as he deems necessary.

6-1012~~3~~.1B The dimensions shown on the typical section are minimum.

6-1012~~3~~.1C The concrete shall be A3 (Class 20).

6-1012~~3~~.1D The subgrade shall be constructed to the required elevation below the finished surface of the paved ditch in accordance with the dimensions and design as shown on the approved plans.

6-1012~~3~~.1E All soft and unsuitable materials shall be removed and replaced with an approved material which shall be compacted to 95% density in accordance with AASHTO-99-61 and finished to a smooth surface.

6-1012~~3~~.1F The subgrade shall be moistened prior to the placing of the concrete.

6-1012~~3~~.1G Ditches shall be formed to true typical section in accordance with the alignment dimensions and design required by the approved plans.

6-1012~~3~~.1H All forms shall be inspected before the placing of concrete.

6-1012~~3~~.1I A minimum 6" (150mm) diameter underdrain shall be placed where excessive ground water conditions are encountered to limits as deemed necessary by the Director.

6-1012~~3~~.1J Underdrains shall be encased in washed gravel.

6-1012~~3~~.1K On curves, the paved ditch shall be formed on the specified curve as indicated on the approved plans.

6-1012~~3~~.1L The finish surface of the paved ditch shall be coarse or roughened texture.

6-1012~~3~~.1M 4" (100mm) weep holes shall be provided as directed by the inspector.

6-1012~~3~~.1N A minimum of 1 ft^3 ($0.03m^3$) of 2" (50mm) washed gravel shall be placed at the mouth of each drain pipe.

6-1012~~3~~.1O The type, dimensions (WxBxD), and limits shall be indicated on the plans.

6-1012~~3~~.1P In the case of special designs, the plans will indicate a typical section with dimensions and the limits to be provided.

6-1012~~3~~.1Q All transitions shall be shown on the plans and the limits indicated.

6-1012~~3~~.1R Ditches shall be reinforced with 6" x 6" No. 6 (152 x 152 - MW 19 x MW 19) welded wire fabric. The welded wire fabric and reinforcing steel, when required, shall conform to the current VDOT Road and Bridge Specifications.

6-1012~~3~~.1S PD-A, B, C & D ditches shown on Plate 19-6 (19M-6) shall be poured in alternate sections of 10' (3m) and no section shall be less than 5' (1.5m). Construction joints shall be provided every 10' (3m) and ¾" (19mm) bituminous expansion material shall be provided every 40' (12m) and shall extend to full depth of slab. The expansion joint filler shall conform to the current VDOT Road and Bridge Specifications.

6-1012~~3~~.1T Curtain walls shall be provided at each end of the paved ditch, and at other locations where undermining can occur. This curtain wall shall extend a minimum of 18" (450mm) below and perpendicular to the grade of the paved ditch. It shall be as thick as the concrete thickness of the ditch slab.

6-1012~~3~~.1U (47-95-PFM) Paved ditches constructed of asphalt concrete shall not be permitted.

6-1012~~3~~.1V Gabions may be used in lieu of paved ditches when approval has been given by the Director. These gabions will be of the Maccaferri or Bekaert type or approved equivalent. Typical gabion uses for channel section, revetment with toe wall and weir section are shown in Plates 21-6 (21M-6) thr~~u~~ough 23-6 (23M-6).